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Accretion, chemical evolution, and differentiation of the terrestrial planets

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Terrestrial planets grow by repeated collisions in a swarm of ~10 km-scale planetesimals and lunar- to Mars-mass embryos. N-body modeling of this process has successfully reproduced many aspects of the Solar System's terrestrial planets [eg. 1,2], although reconciling all of the available evidence is still an outstanding problem [3]. We will give an overview of the current state-of-the-art in the modeling of terrestrial planet formation, with a specific focus on its implications for the chemical evolution and differentiation of terrestrial planets.

Significant radial mixing can occur during terrestrial planet formation, delivering volatile elements into the terrestrial planet region. Large impacts, which are common during the final stages of terrestrial planet formation, can lead to volatile loss. Recent work that combines N-body accretion simulations with a nebula condensation model finds that elements such as Na, P, and S are overabundant in simulated planets, but become much more consistent with Earth's abundances when a simple model of impact heating and volatile loss is included [4]. This may have important implications for the Earth's initial water budget.

Radiogenic and impact heating leads to melting and differentiation of the growing planets, with iron and siderophile elements separating from rocky material and segregating into the core. In addition, many of the large embryos impacting the planets are likely to be differentiated themselves. The Hf-W isotopic system provides a way to understand and date this process, but is subject to some uncertainties, namely the degree to which the cores of the impacting embryos are able to mix and equilibrate with the mantle of the growing planet [5]. Analyzing N-body accretion simulations to track the Hf-W isotopic evolution of the growing planets suggests that a significant degree of equilibration during impacts is necessary to match the Hf-W isotopic signatures of Earth [6]. Constraining Mars' differentiation history is more difficult, although it is clear that it differentiated before the Earth [7].

[1] Chambers (2001), *Icarus* **152**, 205. [2] O'Brien *et al.* (2006), *Icarus* **184**, 39. [3] Raymond *et al.* *Icarus*, submitted. [4] Bond (2008), Ph.D. Thesis, U. Arizona. [5] Rubie *et al.* (2003), *EPSL* **205**, 239. [6] Nimmo and Agnor (2006), *EPSL* **243**, 26. [7] Nimmo and Kleine (2007), *Icarus* **191**, 497.

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Iron oxides are ubiquitous in sediments, aquifers and soils, where Fe(II)/Fe(III) oxidation/reduction cycles couple biotic and abiotic processes. Mixed-valence iron oxides are involved in the degradation of organic matter, nutrients and pollutants and also the adsorption, retention and mobilisation of numerous substances. Due to these diverse interactions, the iron cycle is intrinsic to the water quality of lakes, coastal waters and groundwater.

Currently there still remain surprisingly large gaps in our understanding of the redox transformation reactions of iron oxides. The role of microbial electron transfer to iron oxide surfaces is not well understood, and we do not know how electrons migrate and redistribute in the solids, and to which extent Fe(II) catalyses the transformation of different iron oxide minerals.

RNA-SIP, based on tracing ¹³C from labelled acetate into the DNA and RNA of the active microbial community, has been applied to natural iron rich lake sediments. This allows us to identify which iron reducing bacteria are active. By combining this with experiments using labelled Fe-oxides enables the derivation of a complementary picture of which Fe-oxide phases are used and which are formed.

The natural lake sediment studied is characterized by a high fraction of very labile Fe-oxides in the top few cm compared to further down. Part of the explanation could simply be the removal of the labile part by microbial reduction, but experiments have shown that fast interactions between adsorbed Fe(II) and Fe(III)-oxide minerals often promote total recrystallization in pure systems. Experiments using natural lake sediments and synthetic ⁵⁵Fe and ⁵⁷Fe labelled iron oxides and aqueous Fe²⁺ will be able to track the rates and effects of these transformations in natural systems where Fe²⁺ is produced by microbial reduction.